NUCLEAR STRUCTURE FUNCTIONS AT SMALL x FROM INELASTIC SHADOWING AND DIFFRACTION

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A model for shadowing in nuclear structure functions at small x and small or moderate Q^2 is presented using the relation with diffraction that arises from Gribov's reggeon calculus. A reasonable description of the experimental data is obtained with no fitted parameters. A comparison with predictions from other models is performed.

The study of nuclear structure functions is a very fashionable subject and has a great importance in the analysis and interpretation of results from heavy ion experiments. At small values of the Bjorken variable x ($\lesssim 0.01$, shadowing region), the structure function F_2 per nucleon turns out to be smaller in nuclei than in a free nucleon [1]. Several explanations to this shadowing have been proposed. In the rest frame on the nucleus nuclear shadowing can be seen as a consequence of multiple scattering: the incoming virtual photon splits into a colorless $q\bar{q}$ pair long before reaching the nucleus, and this dipole interacts with typical hadronic cross sections which results in absorption. Multiple scattering can be related to diffraction by means of the AGK rules [2]. Equivalently in a frame in which the nucleus is moving fast, gluon recombination due to the overlap of the gluon clouds from different nucleons reduces the gluon density in the nucleus [3].

Following the first approach, the γ^*-nucleus cross section can be expanded in a multiple scattering series containing the contribution from 1, 2,... scatterings between the probe and the different nucleons inside nuclei:

$$\sigma_A = \sigma_A^{(1)} + \sigma_A^{(2)} + \cdots . \tag{1}$$

$\sigma_A^{(1)}$ is simply equal to $A\sigma_{\rm nucleon}$. The first correction to the non-additivity of cross sections comes from the second-order rescattering $\sigma_A^{(2)}$.

To compute it we need the total contribution which arises from cutting the two-exchange amplitude in all possible ways (between the amplitudes and the amplitudes themselves in all possible manners). It can be shown that, for purely imaginary amplitudes, this total contribution is identical to minus the contribution from the diffractive cut. Thus diffractive DIS becomes linked to the first contribution to nuclear shadowing. The final expression reads

$$\sigma_A^{(2)} = -4\pi A(A-1) \int d^2b\ T_A^2(b) \int_{M_{min}^2}^{M_{max}^2} dM^2 \left. \frac{d\sigma_{\gamma^* \mathrm{p}}^{\mathcal{D}}}{dM^2 dt} \right|_{t=0} F_A^2(t_{min}), \tag{2}$$

with $T_A(b)$ the nuclear profile function normalized to unity, and M^2 the mass of the diffractively produced system. Q^2, x, M^2 and t, or $x_P = x/\beta$, $\beta = \frac{Q^2}{Q^2+M^2}$ are the usual variables in diffractive DIS. Coherence effects, i.e. the coherence length of the $q\bar{q}$ fluctuation of the incoming virtual photon, are taken into account through

$$F_A(t_{min}) = \int d^2b\ J_0(b\sqrt{-t_{min}})T_A(b), \tag{3}$$

with $t_{min} = -m_N^2 x_P^2$ and m_N the nucleon mass. This function is equal to 1 at $x \to 0$ and decreases with increasing x due to the loss of coherence for $x > x_{crit} \sim (m_N R_A)^{-1}$. The lower integration limit in (2) (and (7) below) is $4m_\pi^2 \simeq M_{min}^2 = 0.08$ GeV^2, while the upper one is taken from the condition:

$$x_P = x\left(\frac{M^2+Q^2}{Q^2}\right) \leq x_{Pmax} \Longrightarrow M_{max}^2 = Q^2\left(\frac{x_{Pmax}}{x} - 1\right), \tag{4}$$

with $x_{Pmax} = 0.1$.

Higher order rescatterings are model dependent. Two different ways to unitarize the total cross section have been considered: a Schwimmer unitarization [4] which is obtained from a summation of fan diagrams with triple Pomeron interactions,

$$\sigma_{\gamma^* A}^{Sch} = \sigma_{\gamma^* \mathrm{nucleon}} \int d^2b\ \frac{AT_A(b)}{1+(A-1)f(x,Q^2)T_A(b)}\ , \tag{5}$$

and an eikonal unitarization,

$$\sigma_{\gamma^* A}^{eik} = \sigma_{\gamma^* \mathrm{nucleon}} \int d^2b\ \frac{A}{2(A-1)f(x,Q^2)} \left\{1 - \exp\left[-2(A-1)T_A(b)f(x,Q^2)\right]\right\}, \tag{6}$$

where

$$f(x,Q^2) = \frac{4\pi}{\sigma_{\gamma^* \mathrm{nucleon}}} \int_{M_{min}^2}^{M_{max}^2} dM^2 \left. \frac{d\sigma_{\gamma^* \mathrm{p}}^{\mathcal{D}}}{dM^2 dt} \right|_{t=0} F_A^2(t_{min}) \tag{7}$$

is the key ingredient for shadowing and $\sigma_{\gamma^* \mathrm{nucleon}}$ and $\left. \frac{d\sigma_{\gamma^* \mathrm{p}}^{\mathcal{D}}}{dM^2 dt} \right|_{t=0}$ have been computed through $F_2(x,Q^2)$ and $F_{2\mathcal{D}}^{(3)}(Q^2,x_P,\beta)$ for the nucleon taken from CFKS model [5] for γ^*-p inclusive and diffractive production[a]. Thus, the region of applicability of our model is that of CFKS model i.e. that of small $x \lesssim 0.01$ and small or moderate $Q^2 \lesssim 10$ GeV^2, including photoproduction. Let us notice that our model is devoted to the small x region and therefore no antishadowing or any other effects relevant for $x \geq 0.1$ have been introduced. As at low x the contribution of valence quarks is negligible no distinction is done between protons and neutrons. Also the experimental results have been isospin-corrected, so the comparison of the results of the model with those of experiment is legitimate.

[a] For more details about these derivations, see [6].

Shadowing in nuclei is usually studied by ratios of cross sections per nucleon for different nuclei, defined as

$$R(A/B) = \frac{B}{A}\frac{\sigma_{\gamma^* A}}{\sigma_{\gamma^* B}}. \tag{8}$$

In the simplest case of the ratio over nucleon (equivalent to proton at small x where the valence contribution can be neglected), we get:

$$R^{Sch}(A/\text{nucleon}) = \int d^2b \, \frac{T_A(b)}{1+(A-1)f(x,Q^2)T_A(b)} \ , \tag{9}$$

$$R^{eik}(A/\text{nucleon}) = \int d^2b \, \frac{1}{2(A-1)f(x,Q^2)} \left\{1 - \exp\left[-2(A-1)T_A(b)f(x,Q^2)\right]\right\}. \tag{10}$$

From Eqs. (8) and (9) it is evident that our model also predicts the evolution of shadowing with centrality.

Comparison of our predictions with experimental data at small x from E665 [7,8] is shown in Fig. 1. The agreement with data is quite reasonable taking into account that no parameters have been fitted to reproduce the data. Comparison with other set of data has also been performed (see [6]) obtaining a nice agreement as well.

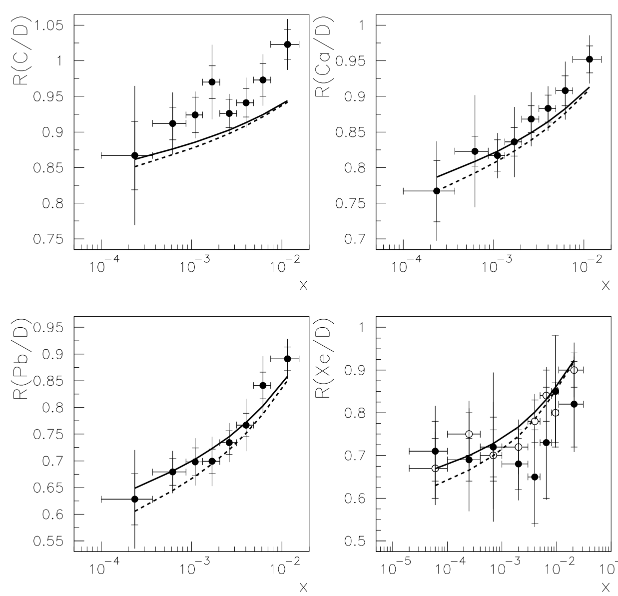

Figure 1: Results of the model using Schwimmer (solid lines) and eikonal (dashed lines) unitarization compared with experimental data, for the ratios C/D, Ca/D, Pb/D [7] and Xe/D [8].

In Fig. 2 a comparison of the results of our model with those of other models is shown, for $Q^2 = 3$ GeV^2. It can be seen that the results of different models agree within 15% at $x = 0.01$ where experimental data exist, while they differ up to a factor 0.6 at $x = 10^{-5}$. Future measurements of $F_{2A}(x,Q^2)$ in lepton-ion colliders with a 10% of sensitivity will discriminate between different models.

Conclusions

A simple model for nuclear shadowing based in the relation between multiple scattering and diffraction provided by AGK rules has been presented. In this way the study of Low x Physics

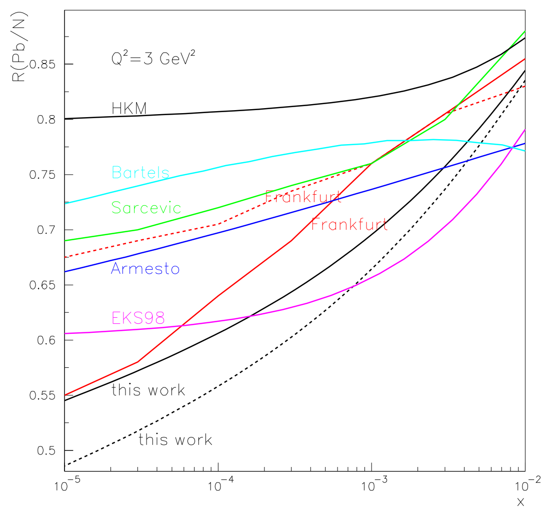

Figure 2: Comparison of the results of our model using Schwimmer (solid lines) and eikonal (dashed lines) unitarization for the ratio Pb/nucleon with other models, versus x at fixed $Q^2 = 3$ GeV^2. HKM are the results from [9], Sarcevic from [10], Bartels from [11], Frankfurt from [12], Armesto from [13] and EKS98 from [14].

at HERA gets linked with that of nuclear structure functions at future lepton-ion colliders and with Heavy Ion Physics at RHIC and LHC.

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